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TROPICAL CYCLONE MINIMUM SEA LEVEL PRESSURE-MAXIMUM SUSTAINED WIND RELATIONSHIP FOR WESTERN NORTH PACIFIC

by

LTCOL GARY D. ATKINSON, USAF
CAPT CHARLES R. HOLLIDAY, USAF

MAY 1975

U.S. FLEET WEATHER CENTRAL GUAM
BOX 12 COMNAVMARIANAS
F.P.O. SAN FRANCISCO, CALIFORNIA 96630

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LTCOL GARY D. ATKINSON, USAF
CAPT CHARLES R. HOLLIDAY, USAF

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U. S. FLEET WEATHER CENTRAL GUAM
BOX 12 COMNAVMARIANAS
FPO SAN FRANCISCO, CALIFORNIA 96630

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ABSTRACT

Determining the proper relationship between the minimum sea level pressures and maximum sustained winds in tropical cyclones has been a long standing problem. The major obstacle has been the lack of sufficient ground truth, i.e., actual measurements of maximum wind speeds in tropical cyclones with a wide range of central pressures. In this study, 26 years of maximum wind measurements made at coastal and inland stations in the western North Pacific were collected and analyzed. Because of problems in measuring and interpreting sustained surface wind speeds, only recorded peak gusts values were used. These peak gusts values were reduced to a standard anemometer level of 10 meters using a power law relationship and then coverted to one-minute sustained wind speeds using gust factors representative of an over water environment. The sample was restricted to those cases in which it was reasonably certain that the station experienced the cyclone's maximum winds during its passage. The resulting equation

$$V_m = 6.7\ (1010 - P_c)^{0.644}$$

where P_c is the minimum sea level pressure (mb) and V_m is the maximum sustained wind speed (knots), indicates maximum wind speeds that are significantly lower than many previous studies.

P sub C

V sub m

V sub m = 6.7 (1010 - P sub C) 0.644

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INTRODUCTION

Developing the proper relationship between the minimum pressure and maximum sustained surface winds in tropical cyclones has been a long standing problem. Physical reasoning indicates there should be a good relationship between the minimum pressure (or pressure difference between the cyclone center and the outer edge of the circulation) and the maximum winds. While numerous equations have been developed over the years, finding a stable equation for this relationship which can stand the test of time in operational use has remained elusive. Reliable center pressures from aircraft reconnaissance have been available for many years; however, accurate observations of the maximum surface winds over water are seldom available. The major problems in obtaining maximum wind observations are the sparseness of oceanic observing stations and lack of adequate wind equipment and exposure at existing stations, anemometers breaking or blowing away before recording the peak winds in intense typhoons, the general avoidance of tropical cyclones by ships and lack of wind measuring equipment by ships infrequently caught near cyclone centers, and the uncertainty of surface wind estimates from sea state observations made during aircraft reconnaissance flights.

In this report, previous studies on tropical cyclone pressure/wind relationships for the western North Pacific are reviewed. A new relationship is developed based on maximum wind observations recorded at island and coastal stations in the western North Pacific area during tropical cyclone passages over the past 26 years. This new relationship has been adopted for operational use by the Joint Typhoon Warning Center.

REVIEW OF PREVIOUS STUDIES

A multitude of minimum pressure/maximum wind relationships for tropical cyclones have been developed over the years for both the North Atlantic and western North Pacific areas. Holliday (1969) surveyed a number of these relationships primarily for the North Atlantic area and developed a new relationship for that area. Most of the relationships for the western North Pacific have been developed by JTWC Personnel and discussed in the JTWC Annual Typhoon Reports (1959-1974). Following is a review of the various relationships which have been developed for the western North Pacific area.

The first equation for relating maximum winds in typhoons to central pressure was developed by Takahashi (1939). He used ship and island wind data near or in Japan during the late 1930's. Since central pressures often were not available, he estimated these by interpolation and a statistical horizontal typhoon pressure distribution model. The following form of the cyclostrophic wind equation was used.

$$V_m = K\ (P_n - P_c)^{0.5} \qquad (1)$$

where V_m is the maximum surface wind speed (knots), P_n is the environmental pressure (mb), P_c is the central pressure, and K is a constant. He chose an environmental pressure of 1010 mb as representative of the western North Pacific area and K was determined to be 13.4. Later, Takahashi (1952) indicated a constant of 11.5 may be more applicable for higher latitudes.

With introduction of aircraft reconnaissance of Pacific typhoons, central pressure observations and estimates of maximum winds near cyclone centers became available. The Typhoon Postanalysis Board (McKnown,et.al., 1952) at Guam derived an equation based on 230 typhoon penetrations during 1951 and 1952. Using Fletcher's equation (published in 1955 but available earlier)

$$V_m = 16\ (P_n - P_c)^{0.5} \qquad (2)$$

as a starting point, a family of curves were developed to fit the reconnaissance data. Fletcher's equation was modified such that the constant decreased linearly with increasing latitude. The resulting equation was

$$V_m = (20 - \theta/5)\ (1010 - P_c)^{0.5} \qquad (3)$$

where θ is the latitude (degrees).

Equation (3) was based entirely on maximum surface wind estimates from sea state observations. No differentiation was made between estimates made from 1500 feet (44% of the data) and those from 700 mb (56% of the data). Flight level winds were not available as doppler navigation systems were not installed on the WB-29's and double drift wind readings were extremely difficult to obtain in typhoons. Procedures for estimating maximum winds from sea state were very subjective and lacked any ground truth verification data. It is not clear how the latitude factor was determined as most of the data were collected near or south of the subtropical ridge. If the cyclostrophic relationship is valid for tropical cyclones, latitude should not be a significant factor. If there is a variation of the wind/pressure relationship with latitude, maximum winds should increase slightly with increasing latitude, for any given central pressure due to the higher environmental pressures, just opposite of the latitude effect indicated by equation (3).

As reconnaissance flights at 700 mbs became routine by the mid-1950's, Fortner (1958) derived an equation relating minimum sea level pressure (MSLP) to the minimum 700 mb height. This equation allowed modification of equation (3) so that 700 mb height values (H_7, given in feet) could be used in lieu of P_c as shown below

$$V_m = (20-\theta/5)\ (372-H_7/28)^{0.5} \tag{4}$$

This change facilitated operational use as the minimum 700 mb height was available and transmitted from the aircraft well before the MSLP computed from the dropsonde observation.

During the early 1960's, several equations were derived using measured 700 mb flight level winds in addition to estimated surface winds. These 700 mb winds became available in 1956 when the WB-50's equipped with onboard doppler navigation systems began operation. The derived relationships also included a latitude factor; however, the Fortner (1958) modification using 700 mb heights was maintained.

Wacholtz (1960) modified the latitude constant based on reconnaissance data from 1956 to 1959. In his relationship, the maximum winds for a given central pressure (or 700 mb height) occurred at 15°N and decreased north and south of this latitude.

Seay (1963) also modified the equation using data through 1962. He changed the latitude factor to $(19-\theta/5)$, close to that of the original 1952 equation. A year later the JTWC staff (1964) modified the 700 mb height term obtaining the resulting equation:

$$V_m = (19-\theta/5)\ (364-H_7/28)^{0.5} \tag{5}$$

In addition to their pressure/wind equations, both Wacholtz and Seay developed equations relating maximum surface winds to the maximum 700 mb winds. These equations, which gave surface winds 10% to 25% higher than the 700 mb winds for typhoons, appear to neglect frictional effects near the earth's surface and probably resulted from overestimates of surface wind speeds from sea state observations.

A later modification of equation (5) was made by the JTWC staff (1968) using land station reports during the 1964-65 and 1967-68 seasons. They noted that winds derived from equation (5) exceeded the maximum winds observed at land stations by 23.4 knots on the average. As a result, a modified graph was constructed by subtracting 20 knots from the values derived from equation (5); however, the graph was considered valid only for wind speeds greater than 45 knots. The land station sample used for this modification was relatively small (22 cases). Also, the data consisted of sustained winds for various averaging periods and varying anemometer heights with no adjustments made for these important differences. In addition, a few of the reports were influenced by terrain effects (e.g., typhoons which had passed over mountainous terrain before passage of the station).

Because of the uncertainty involved in the existing equations and the feeling among JTWC forecasters that they overestimated the maximum winds, the original Takahashi equation was adopted for operational use in the early 1970's. Even this equation, however, appeared to systematically overestimate the maximum winds based on other considerations (e.g., comparison with maximum flight level winds and intensity estimates from satellite data). Therefore, in 1973 a new pressure/wind relationship developed by Fujita, et. al. (1971) was adopted for operational use. While the Fujita relationship appeared to give more realistic wind values, a large scale data collection effort (described in the next section) was initiated to obtain sufficient information to verify or refine the existing relationships.

In this review of equations developed for relating maximum surface winds to the MSLP (or minimum 700 mb height), various problem areas are apparent. These include: (1) the lack of direct surface wind measurements near the cyclone centers, (2) the incompatibility of the surface wind observations used due to various averaging periods, different anemometer heights, and terrain effects, (3) the neglect of boundary layer frictional effects when relating flight level and surface winds, (4) relating wind speed variations for given central pressures to questionable latitude effects, and (5) the inability of the equations to produce realistic maximum winds for the higher pressure ranges.

DATA COLLECTION

The high annual frequency of tropical cyclones in the western North Pacific (Crutcher and Quayle, 1974) coupled with a fair density of meteorological stations along the periphery of East Asia provide the best potential in the world for gathering surface observations during tropical cyclone passages. A major problem, however, is that these specialized observations of peak wind speeds and minimum pressures are not readily available in routine publications from the various countries concerned. Therefore, beginning in 1973, contacts were made through correspondence and personal visits to the various national meteorological agencies to gather the required data. Some of the data were available in climatological summaries published by some countries since the early 1950's. Use was also made of annual reports of tropical cyclones affecting the Philippines (1950-1970), Taiwan (1947-1971), and Hong Kong (1960-1973). Data for Pratas Island were obtained from the Navy of the Republic of China. Special reports which compiled several decades of data on tropical cyclones affecting the Ryukyu and Japanese islands since the 1940's were obtained from the Naha Observatory on Okinawa and the Japanese Weather Association, Tokyo (1973). Occurrences of tropical cyclone passages at meteorological stations operated by U. S. government agencies in the western North Pacific area were screened and data extracted from station records supplied by the National Climatic Center, Asheville, N.C. For recent years (1970 and after), station data were obtained on an annual basis by direct query to the various foreign meteorological services. Because of this extensive data collection effort over a two-year period, it is felt that most of the useable station data collected since just after World War II has been screened for possible inclusion in the data sample. Figure 1 shows the location of stations used in developing the pressure/wind relationship.

METHODOLOGY

In this study, maximum wind observations associated with tropical cyclones occuring at meteorological stations in JTWC's area of responsibility were analyzed and screened for possible inclusion in the data sample. A rigorous set of criteria had to be satisfied before any case was accepted. Out of hundreds of potential candidates occuring during the period 1949-1974, only 76 were selected. Following is a discussion of the criteria used and the rationale for using these criteria.

The primary limiting criterion was that selection was restricted to cases where there was a very high probability that the station experienced the maximum winds in the cyclone durings its passage. This meant that sometime during its passage, the eye wall cloud (where the strongest winds are normally found) must have been over the station. Additionally, since the strongest winds are usually found in the right hand semicircle of the cyclone according to the direction of movement, selected cases were almost always restricted to cases where the cyclone passed directly over or just to the left of the station.

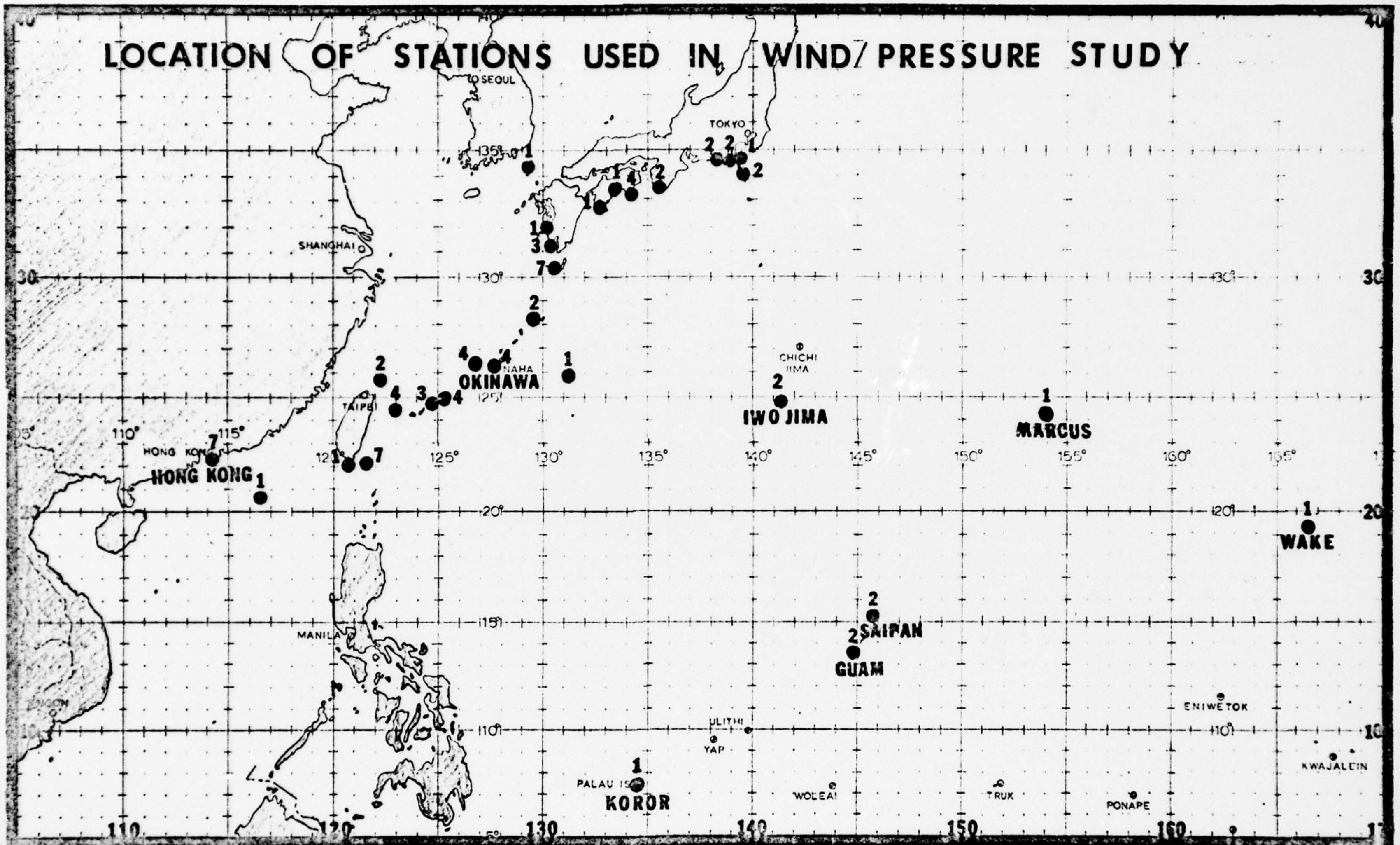

LOCATION OF STATIONS USED IN WIND/PRESSURE STUDY
SEOUL
TOKYO
SHANGHAI
NAHA
OKINAWA
TAIPEI
HONG KONG
MANILA
CHICHI JIMA
IWO JIMA
MARCUS
WAKE
SAIPAN
GUAM
ULITHI
YAP
PALAU IS.
KOROR
WOLEAI
TRUK
PONAPE
ENIWETOK
KWAJALEIN

FIGURE 1

Detailed mesoscale analyses of the cyclone's track and eye diameter as reported by aircraft reconnaissance and land radar observations were used in the selection process. In less intense tropical storms which lack a wall cloud, the maximum winds are usually farther removed from the cyclone center and horizontal wind speed gradients are much less than in typhoons. For these cases, meteorological judgement and analyses of aircraft reconnaissance wind observations were used to determine if the station experienced the cyclone's maximum winds.

The maximum wind values used were restricted to peak gust observations taken at stations with recording anemometers. It is felt that peak gusts are the most reliable wind observation available during strong wind periods. This is illustrated by Figure 2 which shows the wind speed record during Typhoon Tilda at Kadena AB, Okinawa on 2 October 1961. The peak gust of 108 knots is easily read from the recorder roll; however, estimates of the maximum sustained wind speeds for averaging periods of one, five, or ten minutes could vary considerably among independent observers. The restriction of selected cases to stations with wind recording devices is to ensure that the peak wind speed was used. At stations where only wind dials are available, the peak gust could easily be missed due to demanding observer duties during such periods of violent weather. Because of this restriction,many potential candidates from among cyclones striking the Philippines or various western North Pacific island stations had to be eliminated because of the uncertainty in the wind observational accuracy. In addition to the above restrictions, data used in the analysis were limited to wind observations from relatively small islands or to coastal stations where the peak winds blew from an off-shore direction. This restriction was necessary so that, as much as possible, the wind observations would be representative of undisturbed over-water flow. While even relatively small islands will reduce the sustained windspeeds from those of nearby open water, the peak gusts should be affected only slightly. This is because peak surface wind gusts in tropical cyclones invariably occur during periods of heavy rainfall during which maximum winds above the friction layer are transported downward to the surface in the downrush winds caused by the convective activity. As a result, surface friction effects have less time to operate and reduce the maximum wind speeds.

The study was designed to develop the proper relationship between minimum sea level pressure in tropical cyclones and the maximum sustained one-minute average wind speeds over water for operational warning purposes. Thus, the peak gusts for the selected cases had to be adjusted for elevation differences and reduced to one-minute sustained wind speeds

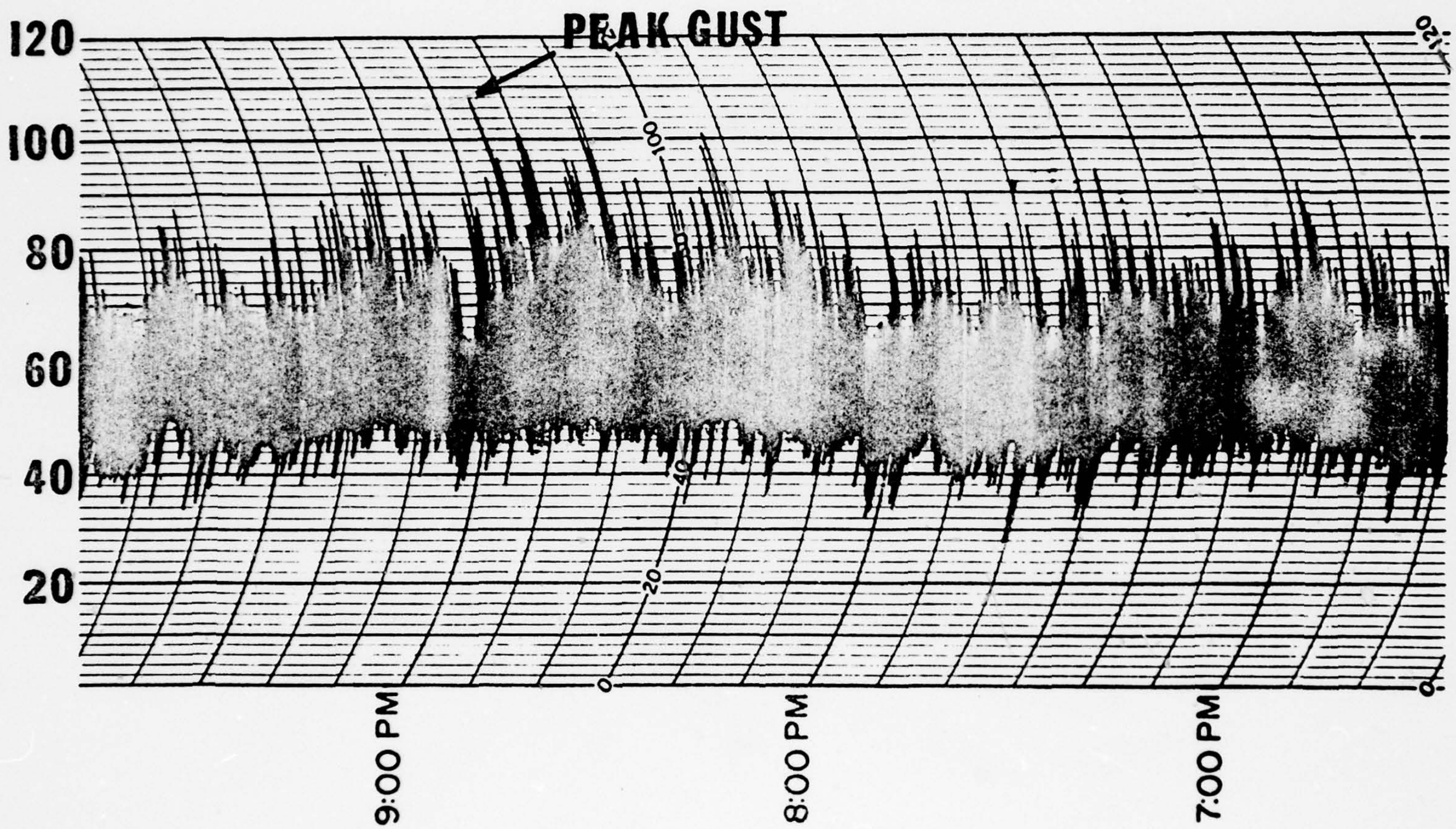


FIGURE 2

using appropriate gust factors. The structure of the wind field near the earth's surface is extremely complex and has been the subject of numerous micrometeorological studies. Fortunately, an excellent survey of near-surface wind structure during strong wind conditions prepared by investigators from the Air Force Cambridge Research Laboratories (AFCRL) was available (Sissenwine, et. al, 1973) and used for determining reasonable adjustment factors.

Studies on the vertical variability of wind speed with height indicate that wind profiles tend to obey the following power law

$$V/V_O = (H/H_O)^{P} \tag{6}$$

where V_O is the wind speed at some reference level (H_O) and V is the wind speed at level (H). The exponent (P) can vary considerably depending on the atmospheric temperature lapse rate, wind speed, and surface roughness. A typical value of P for sustained wind speeds under neutral stability conditions is 1/7 (0.143). The exponent (P) for peak gusts, however, should be much less because of the reduced frictional effects discussed earlier. For this study, a P value of 1/16 (0.0625) as recommended by Sherlock (1952) was used to adjust all peak gust observations to a standard elevation of 10 meters. This P value was the lowest observed in all studies surveyed by the AFCRL report and was chosen to be on the conservative side (i.e., its use gave the least reduction of peak gust speeds with decreasing height). A graph giving the ratio of peak gusts at various levels to the peak gust at 10 meter elevation using the exponent P=0.0625 is shown in Figure 3. The following example illustrates application of this height adjustment. The meteorological station at Andersen AFB, Guam has an elevation of 191 meters above the surface and an anemometer height of 4 meters. Entering the graph in Figure 3 at 195 meter elevation a ratio of 1.20 is found. Thus, peak gusts observed at Andersen in tropical cyclones were divided by 1.20 to estimate the peak gusts that would be observed at the 10 meter elevation.

Once peak gusts were adjusted for anemometer height differences, estimates of the corresponding sustained one-minute wind speeds were made. To do this, recommended gust factors given in Table 13 of the AFCRL report were used. A graph of these gust factors plotted against sustained one-minute wind speeds is shown in Figure 4. It shows the gust factors decreasing with increasing wind speed. This should be expected from physical considerations due to increased instability and turbulent mixing with increased wind speeds. The gust factors shown in Figure 4 are less than the gust factors used operationally

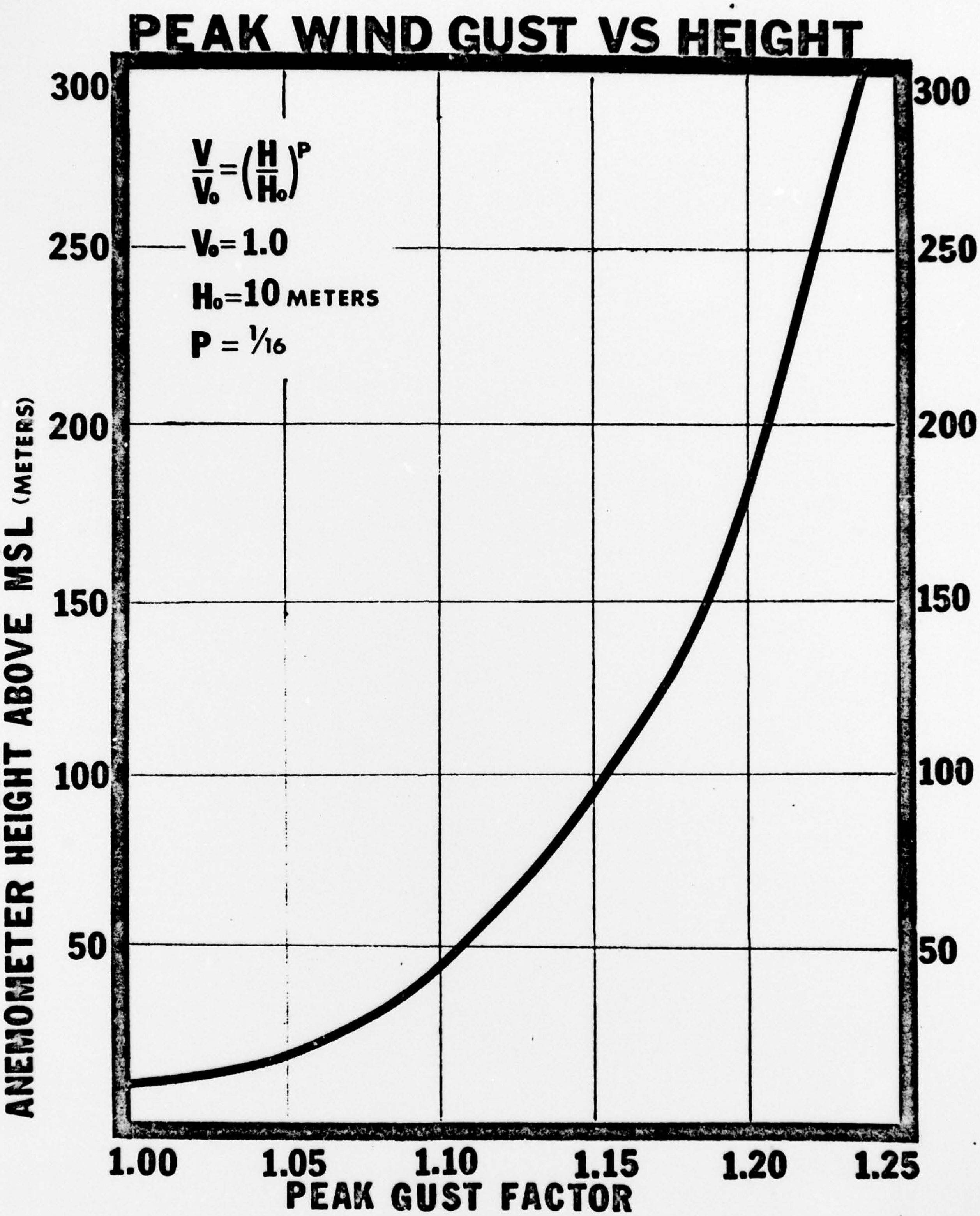

PEAK WIND GUST VS HEIGHT
$\frac{V}{V_o} = \left(\frac{H}{H_o}\right)^P$
$V_o = 1.0$
$H_o = 10$ METERS
$P = 1/16$
ANEMOMETER HEIGHT ABOVE MSL (METERS)
300
250
200
150
100
50
1.00
1.05
1.10
1.15
1.20
1.25
PEAK GUST FACTOR

FIGURE 3

GUST FACTOR VS SUSTAINED WIND SPEED

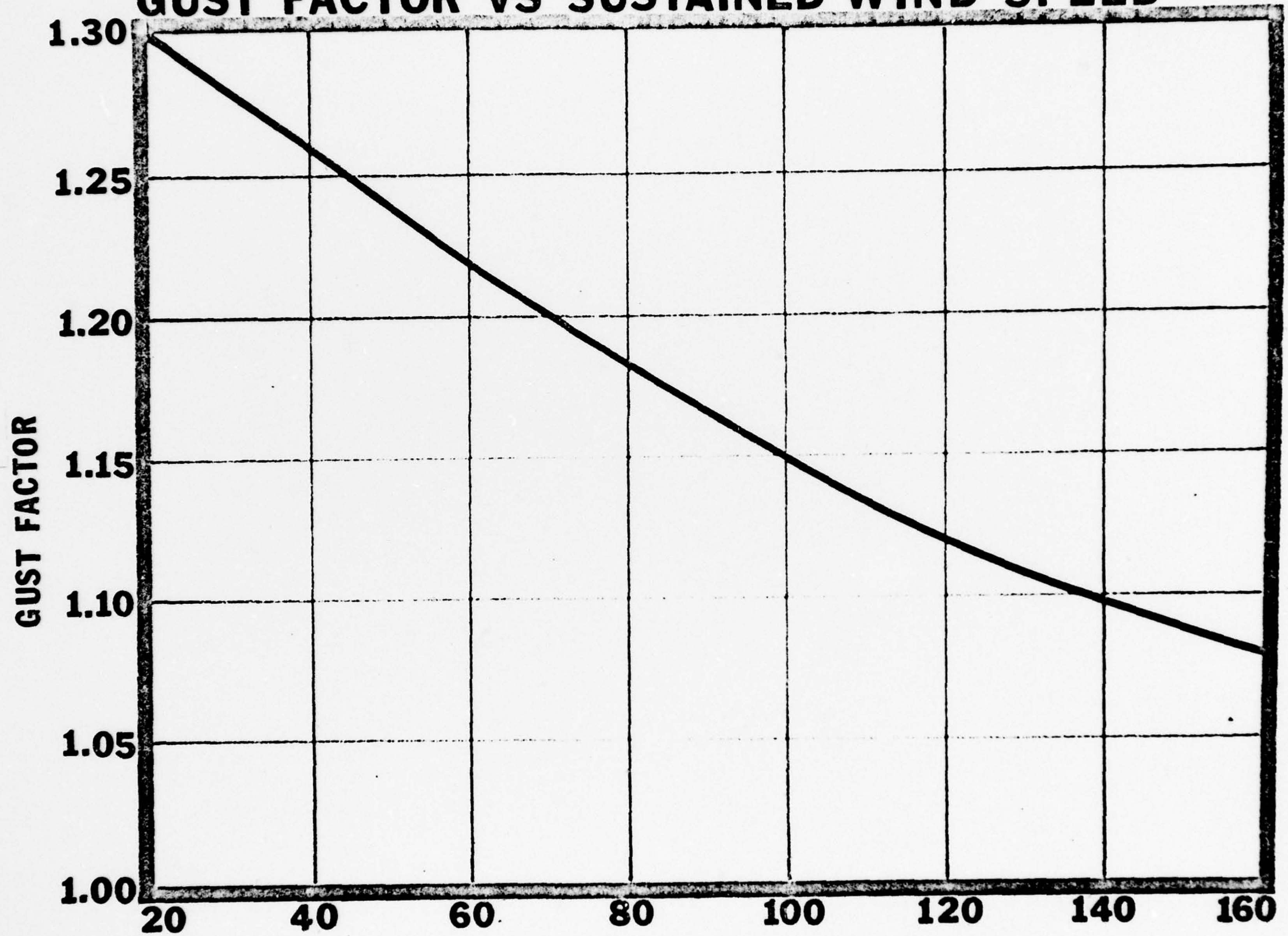


FIGURE 4

by JTWC which vary between 1.25 to 1.20 for winds exceeding 60 knots (Atkinson, 1974). Therefore, their use resulted in less reduction of the peak gusts to sustained winds than would have resulted from using the JTWC operational peak gust factors. Again, the more conservative values were used so that the sustained winds would be overestimated rather than underestimated in case any bias is present.

Once the maximum sustained winds were derived, estimates were made of the minimum sea level pressure (MSLP) in the cyclone at the time the maximum winds were recorded. All available data were used to determine the MSLP. For cyclones that went directly over or very near the station, MSLP could be determined from the station pressure observations. In cases where the center passed more than 10 miles away from the station, the MSLP in the cyclone was interpolated from aircraft reconnaissance observations of MSLP. For island stations these observations were generally available before and after center passage; however, for coastal stations, the last aircraft observation prior to landfall was used if it was reasonably close in time to the time of the maximum wind observation. Various sources of error can affect the MSLP observations, e.g., errors in instrumentation or measurement, errors in interpolating MSLP from nearby stations, and errors incurred when the aircraft dropsonde does not exactly hit the cyclone's surface center. To adjust for the last source of error, MSLP were computed from minimum 700 mb heights in the cyclone (Jordan, 1957) and compared to the MSLP recorded from the dropsonde. The lowest of the two values was generally used for the MSLP. Even with these sources of error, most the MSLP's used in the analysis are probably accurate to ± 5 mb.

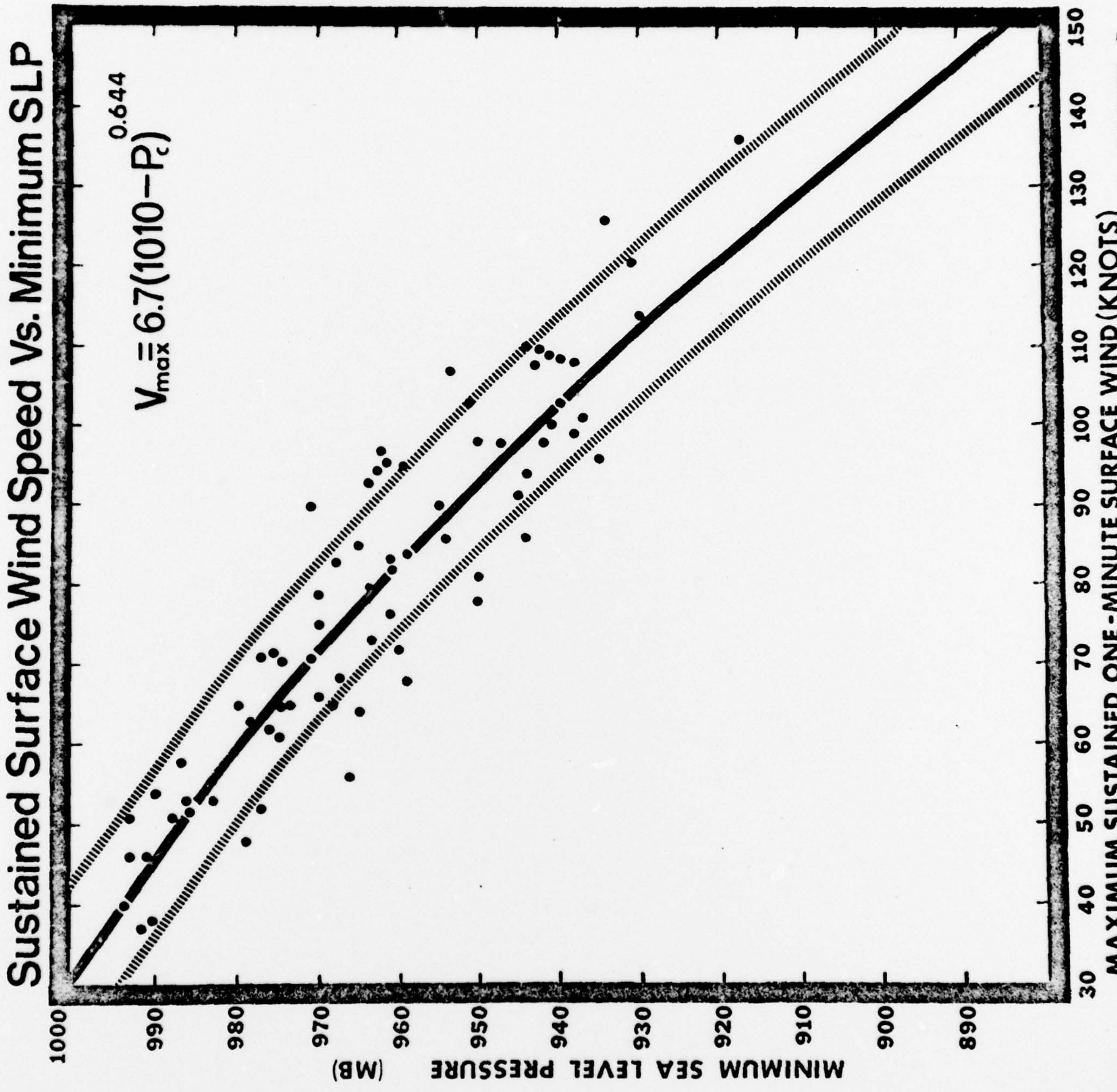
RESULTS

The derived maximum sustained wind speeds are plotted against the MSLP's in Figure 5. Both linear and nonlinear regression equations were fitted to the data points. The nonlinear equation

$$V_m = 6.7\ (1010 - P_c)^{0.644}$$

where V_m is the maximum sustained surface wind speed (knots) and P_c is the MSLP (mb) was selected for two reasons. First, from physical considerations the equation should be similar the form of the cyclostrophic flow relationship shown by equation (1). Most studies of tropical cyclone wind/pressure relationships have used this form of the equation to estimate maximum surface winds. To simplify operational use with little loss of accuracy, a representative value of peripheral pressure is usually chosen. The value of 1010 mb used in several other studies is felt to be representative of the environmental pressure in the western North Pacific area; however, in other tropical cyclone regions other values may be more appropriate. For example, the average environmental pressures near the region of maximum tropical cyclone activity in the North Atlantic is about 10 mb higher than the corresponding area in the western North Pacific. The exponent of 0.644 on the pressure differential term is slightly higher than the 0.5 value used in other studies and implied by the cyclostrophic relationship. The higher values indicates that supergradient winds may be common in the maximum wind zones of intense tropical cyclones. This possibility was discussed by Myers (1957) and later by Shea and Gray (1973). The other reason for selecting the nonlinear form of the equation was that it gave a better fit to the data at the higher pressures and lighter wind speeds. A rule-of-thumb used by JTWC forecasters is that tropical depressions with central pressures near 1000 mb normally have maximum winds around 30 knots and the systems usually develop tropical storm force winds as the pressures drop a few millibars below 1000 mb. In the derived equation, 1000 mb corresponds to winds of 30 knots and 997 mb to winds of 34 knots (minimum tropical storm intensity). Conversely, the best fit linear relationship (V_m=1180.3-1.1436P_c) gives winds of 37 knots for a pressure of 1000 mb.

The nonlinear correlation coefficient for the line of best fit is 0.92 and the standard error of estimate is 8.8 knots. 75% of the cases fall within $\pm$10 knots of the line of best fit (shown by the dashed lines in Figure 5). While the scatter of data points about the regression line is larger than desired, it is considerably smaller than all previous studies of tropical cyclone/wind pressure relationships. It is felt that using the more reliable peak gust observations as the basic wind data input and applying standard adjustment factors for height differences to derive the maximum sustained winds significantly reduced the large scatter found in earlier studies. The remaining scatter is due to departures of individual cases from the standard height and gust factor adjustment values used, the errors in accurately determining the maximum winds and minimum pressures, and differences in wind/pressure relationships in individual cyclones. The last factor can be subjectively adjusted for by JTWC forecasters. For example, a number of tropical cyclones develop each year in the 20° to 30° latitude zone. These cyclones which are normally induced by upper tropospheric lows in the tropical upper tropospheric trough (Sadler,



Sustained Surface Wind Speed Vs. Minimum SLP
$V_{max} \cong 6.7(1010-P_c)^{0.644}$
MINIMUM SEA LEVEL PRESSURE (MB)
1000
990
980
970
960
950
940
930
920
910
900
890
MAXIMUM SUSTAINED ONE-MINUTE SURFACE WIND (KNOTS)
30
40
50
60
70
80
90
100
110
120
130
140
150

FIGURE 5

1964) form in areas of easterly trade wind flow where the environmental peripheral pressure may be significantly above 1010 mb. For these cases, the maximum winds for any given pressure should be expected to be somewhat higher than those derived from the regression equation. Conversely, cyclones which form in the monsoon trough near the Asian mainland may have environmental pressures below 1010 mb and lighter maximum winds than indicated by the equation. These adjustments from the regression equation can be made operationally by considering mean monthly SLP distributions and the current synoptic pressure analysis. Even in these cases, however, it is not advisable to depart more than ± 10 knots from the regression equation value if reliable MSLP observations are available.

It should be pointed out that the MSLP is only one of several techniques used to estimate the cyclone's maximum surface winds. Other tools are intensity estimates derived from applying the Dvorak (1973) technique to visual satellite data and the maximum flight level winds measured by aircraft reconnaissance. The Dvorak technique is far superior to previous techniques for estimating maximum winds from single frame satellite data. In general, it gives a fairly reliable and relatively unbiased estimate of the maximum winds. The main limitation is that its use is currently restricted to once daily visual data. Also, on a few occasions each year, the maximum winds in cyclones have varied significantly from the model estimates which stress the importance of periodic checks on cyclone intensity by aircraft reconnaissance. In well developed tropical cyclones, the maximum flight level winds measured by aircraft reconnaissance are an excellent indicator of the maximum surface winds. In a very comprehensive study using 13 years of aircraft observations of the inner cores of Atlantic hurricanes, Shea and Gray (1973) showed that, in the mean, there is little vertical wind shear between the 900 mb (about 3000 feet) level and the 700 mb level in developing and mature hurricanes due to the vertical momentum transport by the cyclones cumulus convective activity. Thus, the maximum winds observed at the normal flight level of 700 mb should be fairly representative of the maximum gradient level winds. The maximum sustained surface winds, however, must be less than the maximum gradient winds due to surface frictional effects. Assuming the peak gusts observed at the surface in heavy convective activity correspond to the maximum gradient level winds and assuming a surface gust factor of 1.15 the sustained surface winds should be about 85% of the maximum gradient (or 700 mb) winds. Therefore, if it is felt that the aircraft sampled the cyclones peak wind region during radial legs into or out of the cyclone center, the maximum observed flight level winds can be multiplied by 0.85 to obtain a fair estimate of the sustained surface winds.

Aircraft reconnaissance also provides estimates of sustained surface winds from sea state observations. While the surface wind direction estimates are fairly accurate, estimates of the wind speeds are probably the least accurate of all parameters provided by aircraft reconnaissance. The problems of these estimates have been discussed in other sources (Sheets, 1972; Jordan and Fortner, 1960 & 1961) and space does not permit a detailed discussion of the problem areas here. Based on the authors' experience, the surface wind speed estimates appear to be fairly accurate up to speeds of about 50 knots but for greater speeds appear to overestimate the maximum sustained winds based on other considerations. This has been a long standing problem due to lack of ground truth observations needed to revise existing sea state/wind speed tables.

SUMMARY

The graph in Figure 5 is recommended for operational use by JTWC Forecasters to estimate existing maximum sustained surface winds speeds in tropical cyclones from aircraft reconnaissance observations of the MSLP. Also since MSLP values trends normally follow smooth trendlines during the cyclones life cycle, consecutive MSLP observations can be extrapolated forward in time to make fairly accurate forecasts of short term (12 to 24 hr) intensity trends. The derived wind values should be integrated with surface winds estimated from observations of the maximum aircraft flight level winds and satellite estimates of cyclone intensity to derive the final intensity estimate. The maximum winds derived from Figure 5 should also be modified subjectively for anomalous environmental pressure situations as discussed earlier. The cases selected for use in this study are listed in Appendix A. Hopefully, the wind/pressure relationship can be refined and improved in future years as more cases are added to this sample and more accurate techniques for measuring surface winds in tropical cyclones are developed.

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APPENDIX A

CASES USED TO DERIVE MINIMUM PRESSURE/MAXIMUM WIND RELATIONSHIP

Column 1: Name of cyclone
Column 2: Date (zulu time) cyclone hit station
Column 3: International index number of station
Column 4: Peak gust observed at station (knots)
Column 5: Estimated peak gust at 10 meter elevation (knots)
Column 6: Estimated maximum sustained (one-minute) surface wind speed (knots)
Column 7: Cyclones estimated minimum sea level pressure at time of peak gust (mb)
Column 8: Closest point of approach of cyclone to station (nautical miles)

1	2	3	4	5	6	7	8
CARLA	3 May 74	91232	57	57	46	993	10 S
GILDA	4 Jul 74	47929	101	101	86	944	25 W
POLLY	29 Aug 74	47981	108	93	78	950	5 W
WENDY	27 Sep 74	46762	95	76	63	978	5 NW
TESS	23 Jul 72	47897	95	85	71	975	30 WSW
THERESE	1 Dec 72	91408	54	50	40	994	OVER
OLIVE	4 Aug 71	47836	119	111	96	935	10 W
ROSE	16 Aug 71	45xCC*	105	91	76	961	5 W
BESS	22 Sep 71	47918	130	124	109	940	20 SSW
BESS	22 Sep 71	47912	124	113	98	942	OVER
WILDA	13 Aug 70	47909	153	123	108	943	27 W
ANITA	21 AUG 70	47893	105	105	90	955	35 SW
PHYLLIS	22 Jan 69	91218	58	48	38	990	10 S
BETTY	7 Aug 69	47912	105	95	82	961	OVER
BETTY	8 Aug 69	46695	128	110	95	962	30 SSW
CORA	21 Aug 69	47831	103	94	80	964	OVER
FLOSSIE	3 Oct 69	47912	72	65	53	986	10 SE
FLOSSIE	5 Oct 69	47918	66	63	51	993	15 W
POLLY	16 Aug 68	47800	92	85	71	971	25 W
SHIRLEY	21 Aug 68	45xWL*	113	100	85	965	OVER
DELLA	22 Sep 68	47927	155	140	126	934	25 SE
DELLA	23 Sep 68	47929	121	118	103	940	15 NW
DELLA	24 Sep 68	47831	97	89	75	970	15 W
IRMA	22 Oct 68	91232	85	85	71	977	30 WNW
ORA	22 Nov 68	91218	77	64	52	986	10 S
SARAH	16 Sep 67	91245	116	116	101	937	OVER
DINAH	27 Oct 67	47778	94	82	68	967	OVER
LOLA	13 Jul 66	45xCC*	75	65	53	983	15 W
VIOLA	21 Aug 66	47677	74	67	54	990	10 SW
VIOLA	22 Aug 66	47655	64	57	46	991	10 NE
CORA	4 Sep 66	47927	166	150	136	917	15 W
CORA	6 Sep 66	46695	145	125	110	944	22 N
HELEN	23 Sep 66	47836	62	58	47	982	OVER

1	2	3	4	5	6	7	8
IDA	24 Sep 66	47655	98	87	73	963	10 E
KATHY	14 Oct 66	47991	125	125	110	943	5 W
JEAN	5 Aug 65	47823	105	95	81	950	10 W
LUCY	22 Aug 65	47666	90	80	66	970	15 NW
SHIRLEY	9 Sep 65	47899	150	123	108	938	20 W
BETTY	4 Jul 64	47927	108	98	83	968	10 SW
HELEN	1 Aug 64	47836	82	77	64	965	5 SSW
KATHY	23 Aug 64	47836	105	98	83	961	15 W
RUBY	5 Sep 64	45xWL*	124	110	95	962	5 S
SALLY	10 Sep 64	46810	112	112	97	962	10 NE
WILDA	24 Sep 64	47836	133	124	109	941	10 W
SHIRLEY	17 Jun 63	47927	110	99	84	959	OVER
DELLA	28 Aug 63	47676	78	74	61	975	20 SSE
JOAN	9 Jun 62	47929	73	71	58	987	OVER
KATE	22 Jul 62	46762	135	108	93	964	15 NW
LOUISE	27 Jul 62	47778	77	67	55	974	10 WNW
WANDA	1 Sep 62	45xCC*	125	109	94	944	5 S
ALICE	19 May 61	45xRO*	89	79	65	980	OVER
HELEN	29 Jul 61	47945	113	106	90	971	20 W
JUNE	6 Aug 61	46762	141	113	98	950	10 N
LORNA	24 Aug 61	46762	99	79	65	975	OVER
NANCY	16 Sep 61	47899	164	135	121	931	OVER
SALLY	28 Sep 61	46762	106	85	71	975	15 S
TILDA	2 Oct 61	47929	118	115	100	941	OVER
MARY	8 Jun 60	45xWL*	105	93	79	970	10 W
VIRGINIA	9 Aug 60	47981	55	47	37	992	15 W
WENDY	12 Aug 60	47899	74	63	51	988	5 E
CARMEN	20 Aug 60	47936	66	59	48	979	OVER
BILLIE	15 Jul 59	47912	76	69	56	967	OVER
ELLEN	7 Aug 59	47831	85	78	65	968	OVER
GEORGIA	13 Aug 59	47666	124	110	95	959	OVER
ALICE	22 Jul 58	47675	84	69	56	982	10 W
FLOSSIE	25 Aug 58	47899	93	76	62	976	5 W
VIRGINIA	24 Jun 57	46762	132	106	91	945	15 W
BESS	4 Sep 57	47909	91	86	72	960	OVER
BESS	6 Sep 57	47836	126	118	103	951	25 NW
EMMA	8 Sep 56	47936	143	129	114	930	15 SSW
HARRIET	25 Sep 56	47936	112	101	86	954	15 W
IRIS	23 Aug 55	46762	152	122	107	954	15 W
LOUISE	29 Sep 55	47836	122	114	99	938	OVER
MARIE	25 Sep 54	47918	67	64	52	977	OVER
BESS	13 Nov 52	46752	85	81	68	959	12 W
GLORIA	23 Jul 49	47936	125	113	98	947	OVER

*HONG KONG METEOROLOGICAL STATIONS

45xRO - Royal Observatory, 45xCC - Cheng Chau, 45xWL - Wagland Island